Modified Inverted CSRR and Stepped Impedance Stub based Bandstop Filter with wide passband

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ABSTRACT This paper presents a compact bandstop filter (BSF) with a wide passband range (0.1 GHz – 3.7 GHz) and low insertion loss in microstrip technology. The design includes two modified inverted complementary split ring resonators (CSRRs) etched from the bottom plane and L-shaped defected structures along with two stepped impedance stubs placed symmetrically in the top plane. The stop rejected filter has a center frequency of 5.35 GHz which attenuates the signal in the C-band with a fractional bandwidth of 44 %. The designed filter has a circuit size of 0.08 λ_g^2 with a maximum insertion loss of 0.3 dB. The lumped equivalent circuit of the presented filter has been derived and the proposed fabricated BSF structure has also been validated finally with experimental results. This filter with center frequency 5.35 GHz is applicable for rejection of ISM band signals specially Wi-fi (5250 MHz – 5350 MHz) and WLAN (5150 MHz – 5350 MHz) from wide passband signal.

INDEX TERMS Bandstop filter (BSF), Inverted CSRR, Defected structures, Stepped impedance stubs, Wide passband.

I. INTRODUCTION

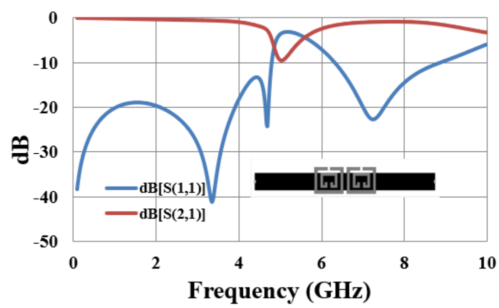
THE communication systems operating at microwave frequencies faces a great concern of signal interference generating noise. The Bandstop Filter (BSF) can eliminate the noise by allowing the signals to pass within the desired band and attenuates the signal out of bands. This filter uses active devices like mixer, oscillator, diplexer to avoid the unwanted higher order frequencies. Microstrip technology is adopted for its ease of fabrication and better performances. The triangular shaped and splitted rings defected structures was employed to design a bandstop filter of dual band [1]. However, stepped impedance resonator could also be realized to design dual band filter [2-7]. But the challenge exists in increased circuit size. This drawback could be eliminated by introducing tri-section stepped impedance resonator (SIR). In [8], the triple section SIR developed compact size, although the selectivity was very poor with large inband loss. Hence, this concept was extended to propose hairpin structures for acquiring better performances [9]. The anti-coupled lines with shorted ends could be designed for achieving BSF with broaden stop bandwidth. The coupled line [10-11] and meander spurline technique [12] could also be adopted to achieve dual and single band bandstop filter [13]. Although, it provided huge passband insertion loss. The triple band bandstop filter

could be formed by cascading three C-shaped ring resonators [14]. The octagonal [15] and rectangular [16] defected ground structures could be designed to obtain miniaturized bandstop filter. The CSRR and other shapes of defected ground structures [17] could be employed for designing microstrip planar filters. Moreover, wideband BSFs can be achieved by connecting two parallel conductors in stripline configuration. An identical structure of basic filter is formed due to the separation of coupled lines [18]. In [19], a 13th order microstrip filter was found to provide good out-of-band emission by using dumbbell-shaped defected slots. The structure was fabricated and applicable in cognitive radio. [20] recommended triangular patch acquiring vertical and horizontal slots on its surface. This provided two-pole and four-pole dual mode bandpass filters. In [21], an ultra-wideband triple notches bandpass filter was configured by implementing elliptical split ring resonator implanted in ring resonator. The interdigital coupled lines were formed in the ground plane and the complete structure shows enhanced stopband-passband characteristics. The coupled lines and transversal filtering section were employed to design wideband dual bandpass filter [22]. Further, the stopband characteristics of the filter was improved by incorporating stepped impedance stubs. The bandpass filters could be designed by complementary split ring resonators (CSRR) [23-24] and slot resonators [25]. The metamaterial ring resonator could also be adopted for the same [26-27].

In this article, the two modified inverted complementary spit ring resonators (CSRRs) are etched to attain a single band bandstop filter from the bottom plane of the substrate. Initially, the splitted ends of the modified CSRR is placed parallel to the microstrip line and is then inverted 90 degree for improving the stopband response of the BSF. The L-shaped resonator in 50 Ω line and two stepped impedance stubs provide wide passband with very low insertion loss and compactness. The filter has been designed with FR4 substrate possessing height (h) of 1.6 mm, loss tangent (tan δ) of 0.02, and dielectric constant (ε_r) of 4.4. The filter has a passband frequency ranges from 0.1 GHz to 3.7 GHz having circuit size of 0.08 λ_g^2 and maximum insertion loss of 0.3 dB. The center frequency of the designed BSF is 5.35 GHz with fractional bandwidth of 44 %. The lumped LC equivalent circuit of the presented design is also derived. Among the experimental and simulated responses, a well-matched performance has been achieved.

II. ANALYSIS AND DESIGN OF BSF WITH WIDE PASSBAND

The complementary split ring resonator acts as a defected ground structure when etched in the ground plane of the substrate. A wide passband with minimal insertion loss as well as maintaining compact size is achieved with formation of L-shaped resonator and stepped impedance stub placed symmetrically in the conductor plane of the substrate. The design method of the BSF is initiated with etching of a rectangular-shaped modified CSRR and then it is inverted 90 degree in the bottom plane of the substrate. A coupling mechanism is also established due to splitted portion facing each other. The simulated responses of the modified CSRR and modified inverted CSRR are represented in FIGURE 1(a) and FIGURE 1(b) respectively. To increase the stop bandwidth with improved rejection level, a L-shaped resonator and two stepped impedance stubs are formed in the signal plane. A parametric study is done for the different dimensions of length (L) (FIGURE 1(c)) and height (h) (FIGURE (d)) of the stepped impedance stubs. The length and height of the stubs are tuned to acquire the optimum requirement with improved performance of the proposed BSF. Table I reflects the effect of filtering parameters for several length of the stepped impedance stub (L). The complete structures of the BSF are depicted in FIGURE 2(a) (signal plane) and FIGURE 2(b) (ground plane). FIGURE 2(c) describes the EM simulated responses of the filter. The first passband upto 3.7 GHz maximum in-band loss is 0.3 dB and in the second passband region (6.7 GHz - 9.41 GHz) is 0.5 dB. Four transmission poles are created at 1.95 GHz, 4.07 GHz, 7.49 GHz and 9.46 GHz. The BSF operates at center frequency of 5.35 GHz exhibiting rejection fractional bandwidth of 44 %.



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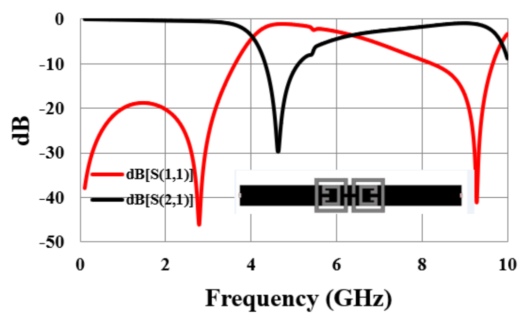

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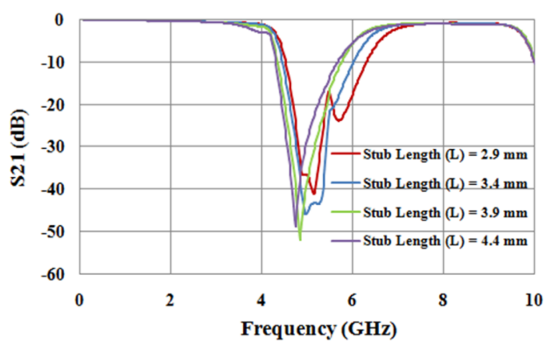

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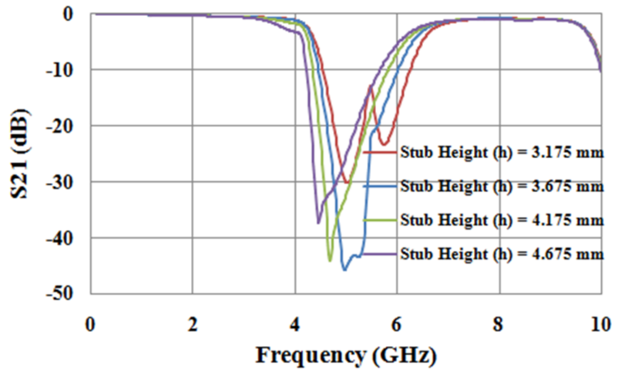

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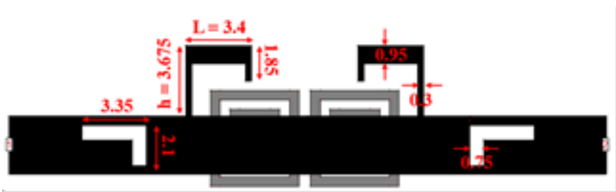
FIGURE 1. Bandstop Filter (a) Modified CSRR (b) Modified Inverted CSRR (c) Simulated responses for different length of stepped impedance stub (d) Simulated responses for different height of stub

TABLE I. Filtering Parameters for Different Lengths of Stepped Impedance Stub (L)

L (mm)	Insertion Loss (dB)	Roll-off Factor (dB/GHz)	Suppression Level (dB)
2.9	0.5	52	-41
3.4	0.3	63	-46
3.9	0.7	65	-50
4.4	1.21	55	-47



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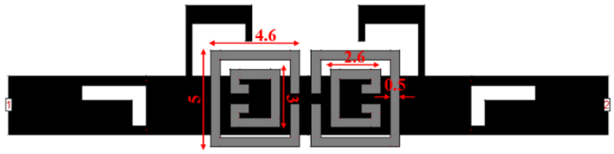

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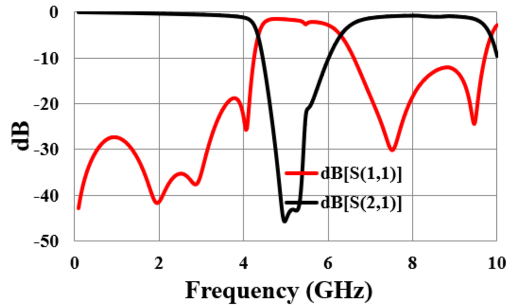


(c)

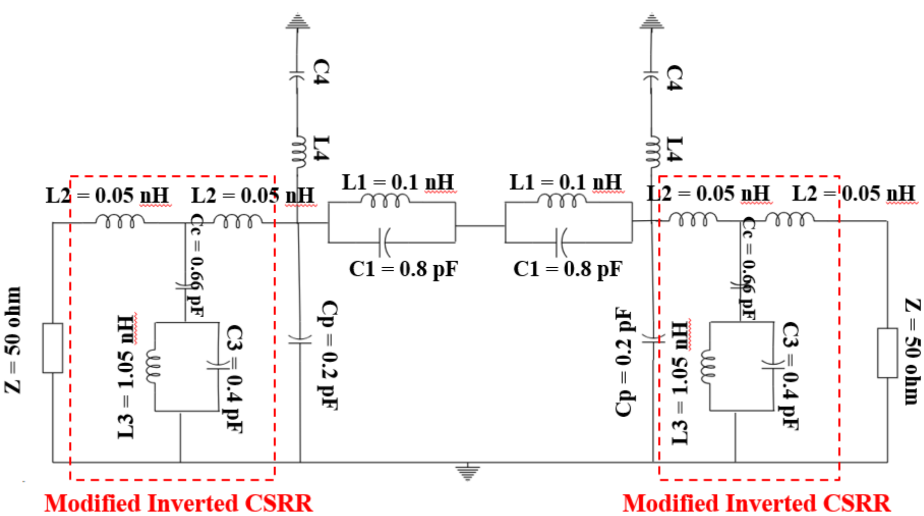
FIGURE 2. Bandstop Filter (a) Conductor plane layout (b) Bottom plane design (c) Simulated responses

The defected structures created inductance and capacitance that can be found as [28]

$$L_g = \frac{1}{4\pi^2 f_o^2 C_g} \tag{1}$$

$$C_g = \frac{f_c}{4\pi Z_o (f_o^2 - f_c^2)} \tag{2}$$

where, the 3 dB cut-off frequency and resonating frequency of a defected structure unit cell are signified by "f_c" and "f_o" respectively. The 50-Ohm characteristic impedance (Z_o) of microstrip transmission line may be found as [28]



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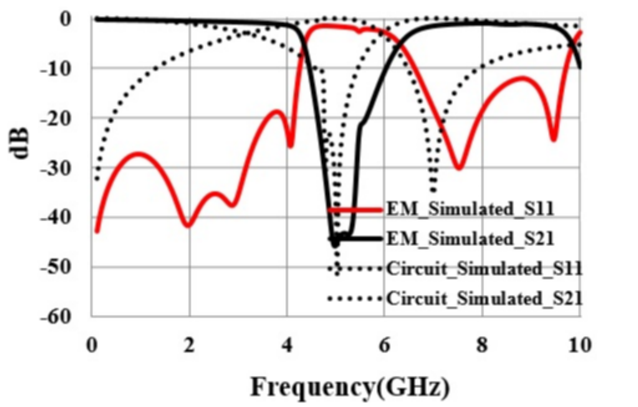


(b)

FIGURE 3. Designed filter (a) Equivalent circuit (b) Circuit simulated vs EM simulated responses

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h}+1.393+\frac{2}{3}\ln\left(\frac{W}{h}+1.444\right)\right]} \text{ Ohms} \tag{3}$$

where, (ϵ_{eff}) is the effective dielectric constant, and $\left(\frac{W}{h}\right)$ denotes the transmission line width and height ratio.

III. CHARACTERISTICS OF THE BSF

The attributes of the designed BSF can be obtained using some well-defined standard equations. The roll-off factor can be found as 63 dB/GHz based on the given equation shown as

$$\xi = \frac{\alpha_{max} - \alpha_{min}}{f_s - f_c} \text{ dB/GHz} \tag{4}$$

where, "α_{max}" and "α_{min}" signify 40 dB & 3 dB attenuation point respectively. "f_c" and "f_s" denote the cut-off frequency & stopband frequency respectively. The fractional bandwidth (FBW) may be obtained by

$$\text{FBW} = \frac{\text{Stop bandwidth}}{\text{Stopband Center Frequency}} \tag{5}$$

where, the center frequency is attained at 5.35 GHz and the stop bandwidth of the designed filter is 2.3 GHz. The FBW of the designed BSF is 44 %. The normalized circuit size of the proposed BSF (0.08 λ_g^2) can be calculated as

$$\text{NCS} = \frac{\text{Physicalsize (length} \times \text{width)}}{\lambda_g^2} \tag{6}$$

The suppression/10 dB is the suppression factor and is obtained on the basis of stopband average suppression which is assumed as 2. The figure of merit (FOM) is measured applying the following equation specified by

$$\text{FOM} = \frac{\text{RSB} \times \xi \times \text{SF}}{\text{AF} \times \text{NCS}} \tag{7}$$

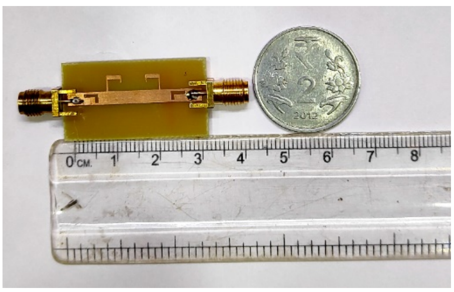
where, the architecture factor (AF) is considered to be "1" for 2D design. The overall index which is known as the FOM of the designed filter is 693.

IV. LUMPED EQUIVALENT CIRCUIT

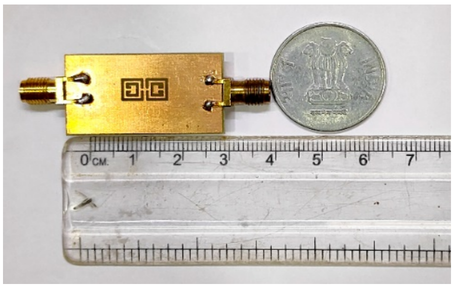
The lumped circuit is extracted for the complete structure of the designed BSF and is presented in FIGURE 2(a). The tank circuit L_3C_3 is generated due to gap and patch in the modified inverted CSRR of the ground plane. The L-shaped resonator is the defected structure in the 50-ohm feedline produces the tank circuit L_1C_1 and $L_4 = 0.8$ nH, $C_4 = 0.1$ pF represents the two stepped impedance stub. The rings of modified inverted CSRR cell rises a coupling capacitance C_c. The circuit modelling is undertaken employing Advanced Design System (ADS) software. The filter exhibits a wide passband broadened up to 3.7 GHz with very low (0.4 dB) insertion loss. The circuit responses and simulated EM results are presented in FIGURE 2(b).

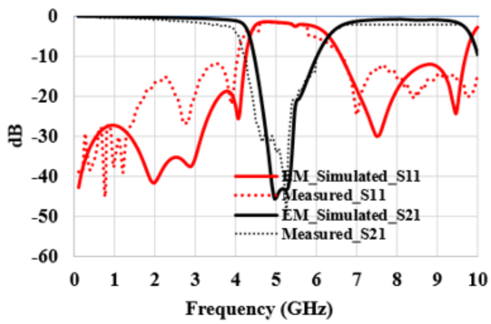
V. EXPERIMENTAL RESULTS

The simulated responses of the designed BSF is validated based on the experimental results. The structure shown in FIGURE 2(a) and FIGURE 2(b) are fabricated utilizing low-cost FR4 substrate. The pictographic design of the fabricated structures for the signal view and ground plane view are represented in FIGURE 4(a) and FIGURE 4(b) respectively. The performance of the fabricated structures is measured using Vector Network Analyzer (VNA). In FIGURE 4(c), the measured vs simulated responses are compared with each other.



(A)





(b)

(c)

FIGURE 4. **Designed BSF (a) Top plane view (b) Bottom plane view (c) EM simulated vs measured results**

The result reflects low insertion loss, wide fractional bandwidth. Even though, a slight discrepancy may be found due to fabrication tolerances and other reliabilities.

VI. GROUP DELAY AND CURRENT DISTRIBUTION

Group delay is used to measure the amount of phase distortion and is proportionate to filter order. The microwave filters are intended to create flattest group delay in the in-band region. But it is not found to be flat due to the characteristics of the Chebyshev filter of exhibiting equi-ripple in passband. The generalized equation for calculating the group delay is inscribed as

$$\text{Group delay} = -\frac{\Delta\phi}{\Delta\omega} \tag{8}$$

Where "φ" represents the S_{21} phase angle and "ω" denotes the angular frequency in rad/sec that is equivalent to $2\pi f$. FIGURE 5 shows the average group delay in the in-band region is less than 0.3 ns.

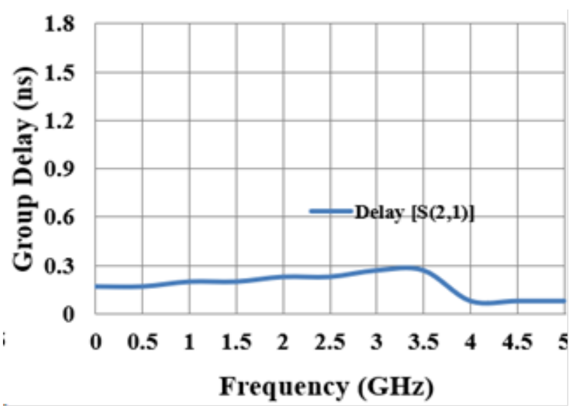


FIGURE 5. Group delay of the designed BSF

The Zealand IE3D electromagnetic software examines the designed filter current distribution at different situations around center frequencies (FIGURE 6). At center frequency 5.35 GHz, an equal input and output current distribution is attained whereas at higher frequencies (8 GHz), the magnitude diminishes.

The performance is compared with some earlier correlated research works which is tabulated in TABLE II. [7] is suffering from large insertion loss. Although [17] provides less circuit size than the proposed work in contempt of more in-band loss. The dual band BSF [10,11] can also been designed using various techniques but suffer from large circuit size.

Hence, in comparison with the Table II, the proposed work has lowest insertion loss, large fractional bandwidth and miniaturized circuit size.

TABLE II. Performance comparison

Ref.	Center Frequency (GHz)	Fractional Bandwidth (%)	Insertion Loss (dB)	Circuit Size (λ_g^2)
[7]	2.4	30	10	NA
[12]	3.8	NA	1.0	0.18
[17]	5.86	NA	0.62	0.06
[10]	1.40, 2.57	12.7, 10.11	9.89	0.24
[11]	0.84, 1.13	22.6, 16.8	0.8	0.10
Proposed work	5.35	44	0.3	0.08

VII. CONCLUSION

In this article, a compact wide passband bandstop filter (BSF) operating at center frequency of 5.35 GHz is designed for rejection of ISM band particularly Wi-fi (5.25 GHz – 5.35 GHz) and WLAN (5.15 GHz – 5.35 GHz). The modified CSRRs are inverted 90 degree to improve the stopband performance of the designed BSF. The stepped impedance stub and L-shaped resonator are placed symmetrically for achieving a fractional bandwidth of 44 % in the rejection band. The filter exhibits a center frequency of 5.35 GHz and a maximum insertion loss of 0.3 dB. The roll-off factor of the designed filter is 63 dB/GHz. This filter provides the benefits of compact size and a wide passband from 0.1 GHz to 3.7 GHz exhibiting low insertion loss.

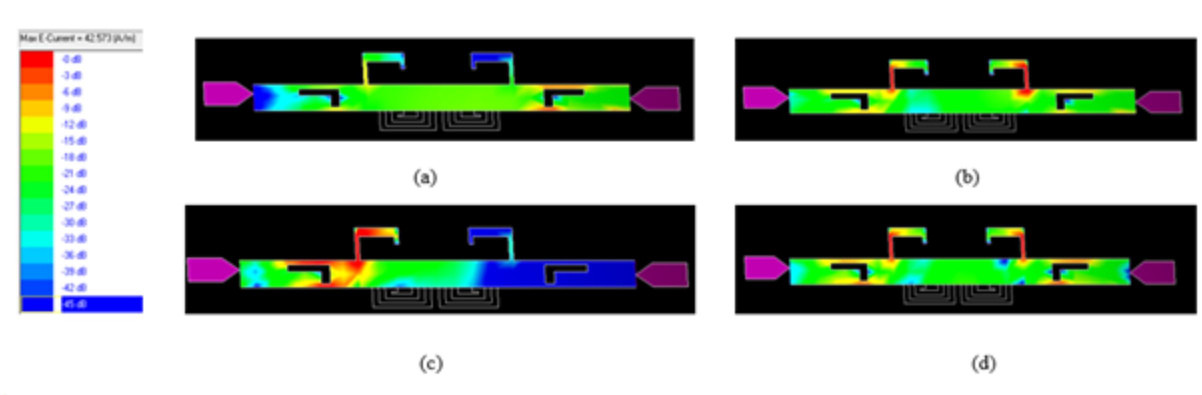


FIGURE 6. Current distribution (a) 1.63 GHz (b) 4 GHz (c) 5.3 GHz (d) 8 GHz

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